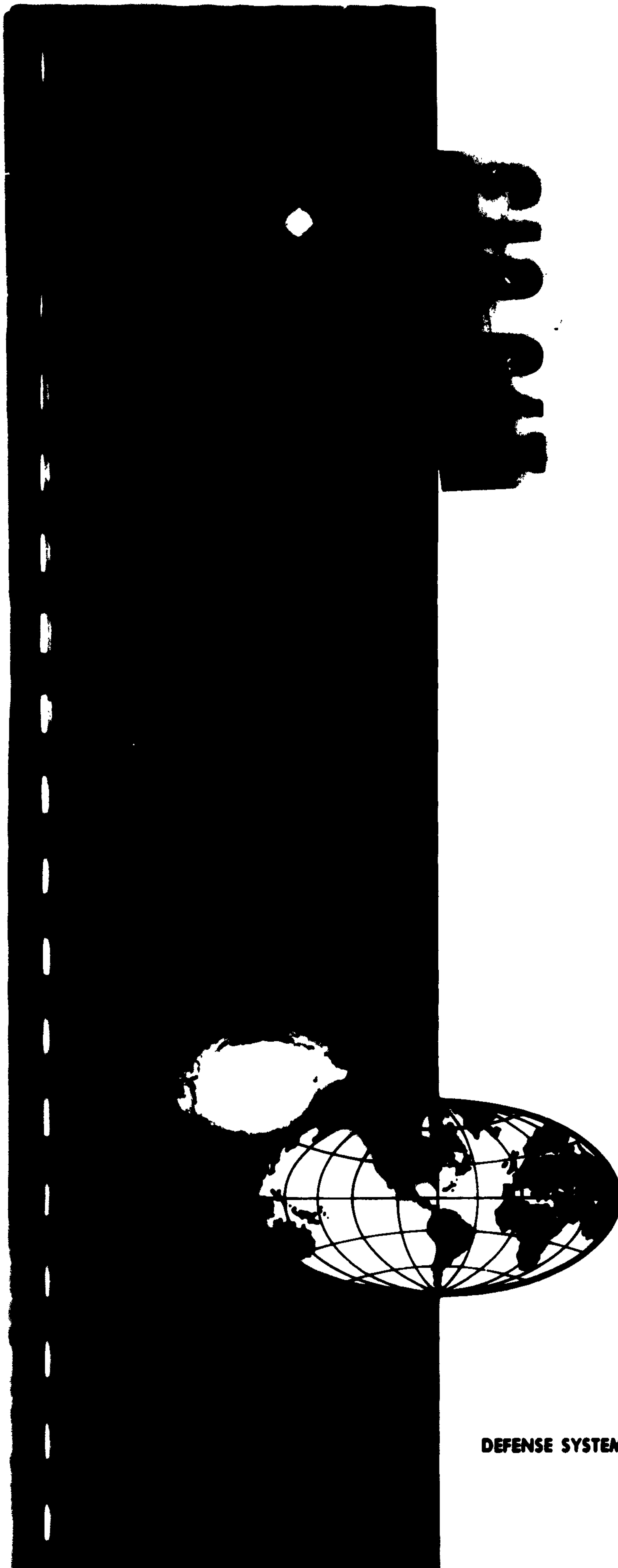

THE J P L DEEP SPACE INSTRUMENTATION FACILITY DSIF

61 SPC-5

SPACE SYSTEMS

DEFENSE SYSTEMS DEPARTMENT • SANTA BARBARA, CALIFORNIA

THE J P L

DEEP SPACE INSTRUMENTATION FACILITY (DSIF)

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61 SPC-5

15 October 1961

SPACE SYSTEMS OPERATION
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I. INTRODUCTION

An integral requirement in the conduct of scientific investigations of outer space is the establishment of a precision tracking and communications system capable of providing command, telemetering, and positional tracking of the space probe. The Deep Space Instrumentation Facility (DSIF) has been established to satisfy this requirement in lunar and planetary programs for which the Jet Propulsion Laboratory (JPL) has been assigned responsibility by the National Aeronautics and Space Administration (NASA). The DSIF is primarily intended for use in experiments conducted at lunar distances and beyond; however, certain experiments in cislunar space may utilize the DSIF stations when schedules permit.

The DSIF is comprised of three Deep Space Stations (DSS's), a mobile station, and the intersite communication links providing for transfer of data and for administration of operations by JPL. A second mobile station is planned for operational use in 1963. The DSS's are presently equipped with 85 ft. diameter reflectors, and can track at angular rates to 1 deg/sec. These large reflectors are used mainly for deep-space experiments. The mobile station is equipped with a 10 ft. diameter reflector, and can track at angular rates to 10 deg/sec. The mobile station is used mainly for command, telemetering, and tracking of space probes from injection to about 10,000 mi. altitude.

The design philosophy of the DSIF is to provide a precision radio-tracking system which measures two angles, radial velocity

and range, and then to utilize this tracking system to send radio commands and to receive radio telemetry in an efficient and reliable manner. The DSIF is scheduled to undergo long-term improvement and modernization consistent with the state-of-the-art and spacecraft requirements. One of the basic design requirements of the DSIF is that it be possible to incorporate these improvements quickly, easily, and economically.

NASA is the cognizant United States agency responsible for the DSIF. JPL, of the California Institute of Technology, is under contract to NASA for the research, development, and fabrication of the DSS's and mobile stations and for the technical coordination and liaison necessary to establish and operate the DSIF throughout the world. Overseas DSS's at Woomera, Australia, and Johannesburg, South Africa, will be operated by personnel provided by cooperating agencies in the respective countries. The Goldstone station and the mobile stations will be operated by United States personnel.

The Goldstone station, in addition to its participation as a member of the DSIF, is utilized for extensive research and development in space tracking and communications. In most cases, new equipment will be installed and tested at Goldstone before it is integrated into the DSIF.

II. HISTORICAL BACKGROUND

In the spring of 1958 the Army was instructed by ARPA to proceed on a lunar program consisting of two firings of a Juno II vehicle, the first firing to be before the end of 1958. The Goldstone tracking station (named for Goldstone dry lake which is 45 miles north of the town of Barstow, California), was designed, constructed, and operated within this time span by JPL to provide deep-space communications for the Army's lunar program. The antenna selected was an 85 ft. diameter, polar-mounted radio-astronomy antenna which was available within 6 months at an established price. The design had been underway for more than 5 years, having been started at the Naval Research Laboratory, carried farther at Carnegie Institute, refined by the associated universities, and completed by the Blaw Knox Company just in time for the Army lunar program. The receiver system was based upon the phase-locked-loop technique of coherent detection. It was constructed by modification of components of a previously proven JPL radio-guidance system. The original equipment had been fabricated for JPL by Motorola-Phoenix and was modified for deep-space tracking by the Collins Radio Company.

In addition to the Goldstone installation, a launch station was installed at AMR and a mobile tracking station was built and shipped to Puerto Rico. The system was code named TRACE (TRacking And Communications, Extraterrestial). The vehicle

had a 960.05 mc transistorized transmitter. The AMR station received one-way doppler information for approximate trajectory determination. The Puerto Rico station first received the TRACE signal within 5 minutes after take-off from AMR and tracked the vehicle for the next 6 to 8 hours until it appeared over the local horizon at Goldstone. The AMR station was a simplified version of the deep-space station consisting essentially of only the receiving channel coupled to a manually pointed parabolic antenna. The Puerto Rico station represented a fully mobile version of the deep-space station except that the antenna diameter was 10 ft. instead of 85 ft. and the servo system was a modified Nike I rather than the JPL deep-space design.

The DSIF has now expanded to a second 85 ft. antenna (for space-craft command) at Goldstone and 85 ft. tracking antennas at Woomera, Australia, and near Johannesburg (Krugersdorp), South Africa. Future plans call for the installation of 250 ft. T-R antennas at each of the above three locations. The Goldstone station is operated by Bendix personnel; the overseas stations by local scientific groups. A large amount of the DSIF electronics equipment was designed for JPL by the Collins Radio Company. Goldstone is only 3 hours by automobile from JPL and has been used as a testing station for new equipment and for JPL experiments.

III. STATION LOCATIONS

The three DSS's are spaced at approximately equal intervals of longitude around the Earth and are located as shown in Table 1.

Table 1. Deep-Space Station Locations

DSS Location	Code	Geodetic Latitude	Longitude
Goldstone, Calif., USA	GS	35.389° N	116.848°W
Woomera, Australia	W	31.382° S	136.886°E
Johannesburg, S. Africa	J	25.891° S	27.675°E

The mobile stations will, in most cases, be located so as to cover the injection point and immediate post-injection trajectory of the spacecraft, which tend at the present time to be centered in the Southern Hemisphere.

The overseas DSS's are located in open plains with average horizon masks (minimum elevation angles) of about 5°. The Goldstone station is in a low spot to minimize RF interference from Los Angeles. Consequently, Goldstone has a horizon mask of about 6° to the south and 40° to the north. The field of view of the mobile stations is somewhat less restricted because they are normally placed at elevated locations.

IV. SYSTEM CAPABILITIES

In the charts and text in this section, the code (I) after the year designates existing installed facilities, (A) designates authorized and funded projects, and (P) designates proposed but not yet funded projects. Particular station configurations will vary somewhat from site to site and are not described in this Memorandum. Such configurations are shown in applicable program documents.

A. Tracking Data

1. Angle Tracking

The automatic-angle-tracking systems used in the DSIF are of the simultaneous lobing type. The 85 ft. Ha-Dec antenna has two maximum tracking-rate capabilities, 1.0 deg/sec and 0.03 deg/sec, depending on tracking system bandwidth requirements. During the periods in which angle-tracking accuracy is most significant (e.g., when data for midcourse maneuver computation and for initial ephermeris calculation are acquired), the strong signal levels available result in a root-mean-square (rms) angle-tracking error from 0.01 to 0.02 deg. The rms tracking error at receiver threshold increases to approximately 0.05 deg. Bias errors are also of this magnitude; however, results of star-tracking data have, for the most part, made possible the stripping out of these bias errors.

The 10 ft. Az-El antenna has a maximum tracking rate capability of 10 deg/sec. Angle errors during post-injection

tracking are usually no greater than 0.1 deg rms. Angle data from all DSIF antennas are digitally encoded directly from the servo-positioning system and routed to the data-handling facility. Angle data as sent to the Central Computer Facility are smoothed only by the noise bandwidth of the servo-tracking system.

2. Range Tracking

A ranging system is presently under development by JPL and is planned for operational use with a 2115/2295-Mc transponder. The system measures the time difference between two identical, separately generated, pseudo-random noise codes (one generated at the transmitter for modulation and the other at the receiver for correlation detection) to represent range. The spacecraft transponder utilizes the same correlation technique to reconstruct the code sequence before retransmission to Earth. Unambiguous ranging at interplanetary distances is planned, with a range resolution equivalent to 0.1 μsec (± 100 ft). The standard transmitting and receiving equipment located at the DSS's will be adaptable to the ranging mode. The ranging detection system is operable as long as carrier coherence is maintained in the two-way system. The general mode of operation for the ranging system will be to establish range lock, and then to remove range modulation and count carrier doppler cycles to maintain the range tally. Present plans require that telemetry, television, and command systems be inoperative during ranging modulation.

DSIF ranging capability at all stations is planned for March 1963 (P). An advanced-development prototype of the ground portion of the ranging system is expected to be in operation at Goldstone in July 1962 (I). The spacecraft portion is expected to be in operation at Goldstone in July 1962(I). The

spacecraft portion is expected to be operational in 1964-1965 (P) to satisfy flight-program requirements arising at that time.

3. Doppler

One-way and two-way radial doppler measurement capability is to be included in the DSIF. Two-way doppler requires a ground transmitter in the vicinity of the receiver to achieve frequency control by a single exciter. The distance at which the DSIF stations can obtain doppler data is, of course, dependent on the sensitivity of the spacecraft receiver and power output of the spacecraft transponder; as long as the carrier can be locked, doppler can be made available.

The accuracy of one-way doppler data is limited because of unknown spacecraft oscillator drift. In the two-way system, the frequency control is maintained by the ground-transmitter exciter and is precisely known. One-way doppler is extracted at an equivalent 31-Mc carrier frequency; two-way doppler is extracted at an equivalent 32-Mc carrier frequency. Two-way precision doppler is available with the shift at the RF carrier frequency (960 Mc or 2300 Mc). Because of the increasing percentage effects of systematic errors (e.g., refraction), it appears that 0.17 m/sec rms is the practical radial-velocity measurement accuracy at present (see Table 2).

Table 2. DSIF Programmed Doppler Capability

Type	Equipment resolution m/sec	Year Operational in DSIF GS	W	J	Mobile Station
One-way	10	1960 (I)	1960 (A)	1961 (A)	1960 (I)
Two-way	5	1960 (A)	1962 (P)	1962 (P)	1960 (A)
One-way precision	0.34	1961 (A)	1962 (P)	1962 (P)	1961 (A)
Two-way precision	0.17	1961 (A)	1962 (P)	1962 (P)	1961 (A)

Cumulative doppler counts can be supplied to eliminate round-off error.

4. Data Handling

Automatic data-handling equipment is presently operational at Goldstone, Woomera, and the mobile tracking station; it will be operational at all DSIF stations in 1961. Data format is such that 120 characters can be printed out per line. The system is presently capable of tape-punching 60 characters per second; however, the intersite teletype communication system can transmit a maximum of 6 characters per second. The present system transmits doppler data, data condition, station identification, time and two angles every 10 seconds. Sample rates from one per second to one per 90 minutes are available. When the ranging capability is added to the DSIF, range will be included in the teletype format.

Transfer of telemetering data from overseas DSS's to JPL may be accomplished in several ways, depending on the urgency of its use. The normal method will be to airmail the telemetry tapes

to JPL, with the attendant delay of approximately 72 hours. Other more rapid methods include use of the teletype system after the completion of the particular DSS tracking mission, and use of commercial radio-telephone facilities. At the present time, local reduction and re-transcription of data is necessary when teletype or radio-telephone methods are used.

B. Communications Data

1. Telemetry

The present ground-telemetering system can accept transmission bandwidths of 3.5 kc and is designed to process FM/PM modulation. A wide bandwidth (1-3 Mc) detection capability is presently under consideration and is planned for integration into the DSIF as part of the 2295-Mc receiver. In most instances, the method of subcarrier detection and the logical design of the ground-station telemetering system will be dictated by the requirements of a particular space-probe experiment, and will vary from mission to mission. As a minimal capability, however, IRIG subcarrier channels 1 through 3 are presently incorporated in the DSIF. Goldstone and the mobile station have available, IRIG channels 4 through 7 also. Phase-lock subcarrier detection techniques are utilized.

2. Command

To provide for the interrogation or command of a space probe, an initial command capability consisting of three audio-frequency tones will be provided in the 1961-62 (A) period. Future command requirements appear to favor a digital technique, and this digital command system will probably be introduced to the DSIF in 1962 (P). Again, as in telemetering, command capability

is closely related to the requirements of individual space-probe experiments, and in most instances the command unit - DSIF interface will consist of a transmitter phase-modulator.

3. Recording Equipment

The recording equipment installed or programmed for installation at each DSIF site is designed to allow recording of a variety of signals, both spacecraft and locally generated. The types of available equipment are shown in Table 3. Signal-conditioning equipment of various types is also provided.

Table 3. DSIF Programmed Recording Equipment

Location	Year Operational in DSIF					
	Direct Writing (8-channel)	Photographic Oscillograph (36-channel	Photographic Oscillograph (14-channel)	Tape Recorder (CEC-752 type)	Video tape recorder (FR-700 type)	Digital recorder
GS	Jan 1960 (I)	Dec 1960 (I)	Dec 1960 (I)	Dec 1960 (I)	July 1961 (A)	Jan 1962 (P)
W			Dec 1960 (I)	Dec 1960 (I)	Jan 1962 (P)	Jan 1963 (P)
J			Apr 1961 (A)	Apr 1961 (I)	Jan 1962 (P)	Jan 1963 (P)
Mobile station		Dec 1960 (I)		Dec 1960 (I)		

The timing system available at each site is stable over a one-day period to 5 parts in 10^{10}. Local time read-out is synchronized to WWV to at least 10 ms, and, at Goldstone, WWV synchronization is usually better than 1 ms. Time read-out is available locally in digital and visual display, and serial coded time is available at 1-sec, 1-min, or 1-hr read-out intervals. Maser timing and frequency control systems are under consideration for use in the DSIF in the 1963-64 period.

4. Special-Purpose Equipment

The major part of the DSIF equipment is or will be standardized for the purpose of reducing spares costs; insuring equalized high performance; and allowing standard training, maintenance, checkout, and countdown procedures to be utilized. Such standardized equipment is designated as Goldstone Duplicate Standard (GSDS). Certain situations exist, however, in which fund limitations and/or program and schedule requirements preclude a GSDS designation; such equipment may be peculiar to any of the DSS's, depending on the need of a particular program.

In general, special-purpose communications equipment is limited to modulation, demodulation, and data-handling equipment specifically required to satisfy a particular program need. Funding and engineering of this special-purpose equipment is handled as part of, and is the responsibility of, the program using it; however, spares requirements, interface configurations, operational procedures, etc., must be coordinated through the DSIF. Facility negotiations and schedules are the responsibility of the DSIF. Operation of specialized equipment is decided by mutual agreement. Some of this specialized equipment, if its use has

shown it to be efficient and reliable and it appears to be versatile in its application to many programs, may later be integrated into the DSIF as GSDS.

5. Intersite Communications

A NASA-operated communications net linking the DSIF stations is utilized for data transfer and for operational control of the DSIF by JPL. The capability that will exist in the 1960-62 (A) period is shown in Figure 1.

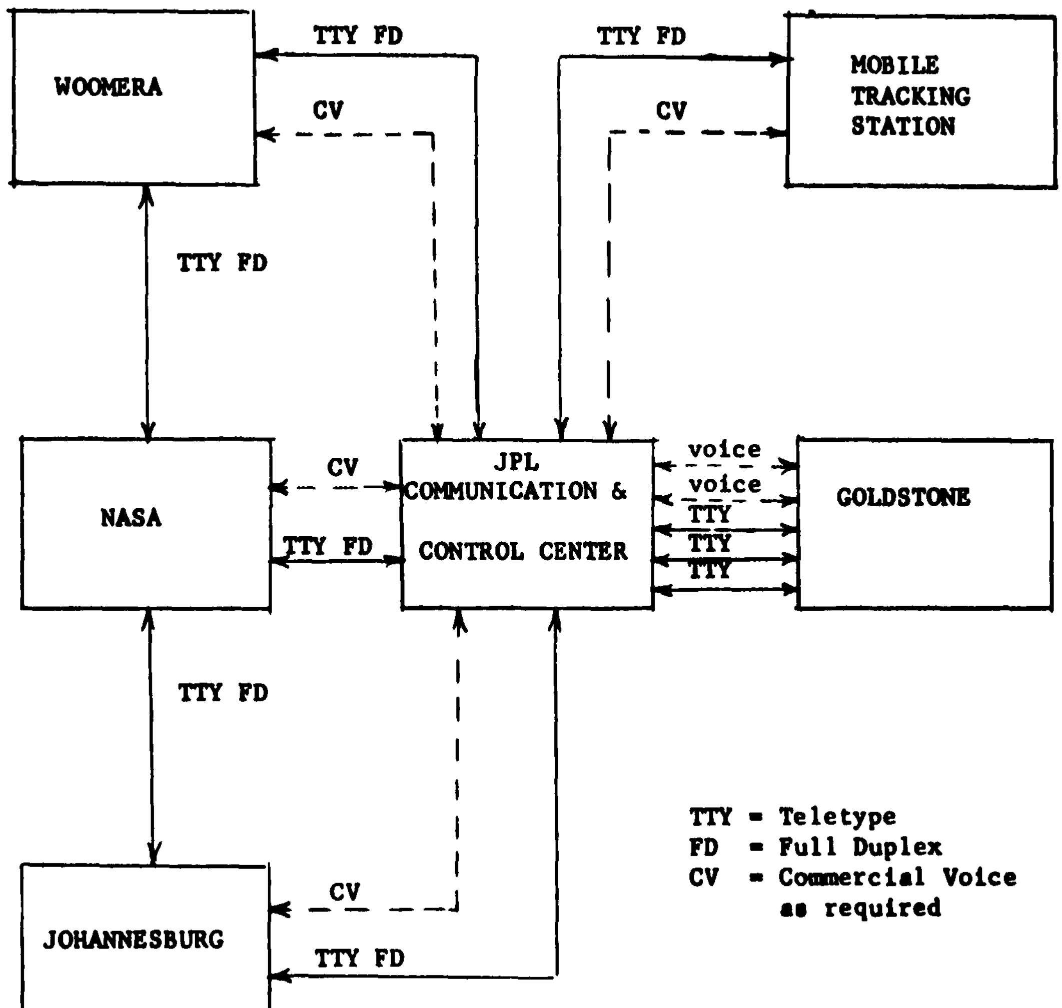

Figure 1. Communications net linking the DSIF stations

A high-frequency system linking the DSIF stations is under consideration for operational use in the 1963-65 (P) period. Band-width capability for this system is planned to be in excess of 3 kc. Communications reliability of 85 to 90% is anticipated.

C. Communications Systems

1. DSIF Frequencies

Frequencies assigned to JPL for use on DSIF missions fall into two general categories: ground-transmitter frequencies and spacecraft-transmitter frequencies. Table 4 shows the allocated and tentatively allocated JPL space-mission frequencies.

Table 4. JPL Space-Mission Frequencies

Frequency, Mc	Year Operational in DSIF	Use
890	1960-63	Transmitter frequency for DSIF equipment (25 w to 10 kw). Receiver frequency for spacecraft equipment
960	1960-63	Receiver frequency for DSIF equipment. Transmitter frequency for spacecraft equipment (1/4 to 100 w).
2115 ± 5	1963	Transmitter frequency for DSIF equipment (25 w to 100 kw). Receiver frequency for spacecraft equipment. The exact frequencies have not yet been chosen, but are expected to be from 6 to 10% lower than the assigned 2290 to 2300 Mc band. (Six to ten percent higher frequency is also under consideration.)
2295 ± 5	1963	Receiver frequency for DSIF equipment. Transmitter frequency for spacecraft equipment (to 1 kw).

A general receiving capability is under consideration for the purpose of receiving and recording telemetry data in the 20-Mc to 10-kMc region. Initially, it is planned to develop and/or incorporate broadband feeds, tunable receivers, wideband-telemetry detection channel, and wide-bandwidth recording systems into the DSIF. This capability is being considered so that the DSIF may react efficiently to requirements for tracking space probes other than those under JPL mission cognizance.

2. DSIF Transmitters

Transmitter capability is incorporated in the DSIF for the purpose of providing two-way doppler data and ranging data and for command of the spacecraft. Depending on the particular mission, power outputs for 25 w to 10 kw are planned. In general, the transmitters will have a phase-modulation capability and will be excited with a voltage-controlled oscillator operated in the 30-Mc region. In some instances, diplexed operation, with a receiver operating at a different frequency, will be employed. Presently under consideration, is a 100 kw transmitter installation for the DSIF. Table 5 indicates the present and future planned transmitter capability.

Table 5. DSIF Programmed Transmitter Capabilities

Frequency Mc	Power output	GS	Year Operational in DSIF		Mobile station	Antenna
			W	J		
890	25w				Dec 1960 (I)	10 ft. Az-El
890	200w	Jun 1961 (I)				85 ft. Az-El
890/960	10 kw	Dec 1960 (I)				85 ft. Az-El
890	200 w		Aug 1962	Aug 1962		85 ft. Ha-Dec
2115 ± 5	10 kw	Dec 1960 (I)				85 ft. Az-El
2115 ± 5	25 200 w				Jan 1963 (P)	10 ft. Az-El
2115 ± 5	10 kw	Jul 1962 (P)	Jan 1963 (P)	Jan 1963 (P)		85 ft. Ha-Dec
2115 ± 5	100 kw	1963 (P)	1965 (P)	1965 (P)		85 ft. Az-El

3. DSIF Receivers

The DSIF stations incorporate extremely sensitive and stable receivers which are designed for the purpose of tracking the received RF carrier in phase, and for amplitude and phase-sensitive detection of the sidebands. The various receivers listed in Table 6 are comprised of a low-noise pre-selector/mixer, carrier and sideband IF amplifiers, detectors, and a voltage-controlled local oscillator, the combination comprising a double superheterodyne receiver, which is locked in phase to the received signal. Doppler data are derived from the local oscillator, telemetry data from either the phase error in the tracking loop or from a separate detection channel, and angle data from separate angle-error detection channels.

Minor modifications of the receiver will be necessary to incorporate the ranging system. In general, correlation detection of the range code will be accomplished at the first mixer, with the bulk of the ranging equipment being separate from the receiver.

Table 6. DSIF Programmed Receiver Capabilities

Frequency	Year Operational in DSIF							Receiver system excess noise °K	Type	Bandwidth	
	Goldstone		Woomera		Johannesburg		Mobile station			Carrier loop noise cps	Telemetry channel information
	1	2	1	2	1	2					
960	Dec 1960(I)	May 1961(A)	Dec 1960(I)		May 1961(A)		Dec 1960(I)	1430	Track	20-250	0-3.5 kc
960	Jan 1962(A)	Jan 1962(A)	Jan 1962(P)		Jan 1962(P)			220-70	Track	20-250	0-5 kc
2295 ± 5	Jul 1962(P)	Jan 1963(P)	Jan 1963(P)	Oct 1963(P)	Jan 1963(P)	Oct 1963(P)		235/50	Track	3-250	0-1 Mc
2295 ± 5							Jan 1963(P)	1000	Track	20-250	0-1 Mc
2295 ± 5	Jul 1964(P)		Dec 1966(P)		Dec 1966(P)			20	Listen	3-250	0-1 Mc

4. DSIF Antennas and Feeds

a. DSIF antenna reflectors - antenna reflectors installed or programmed for installation in the DSIF are shown in Table 7.

Table 7. DSIF Programmed Antenna Reflectors

Pointing accuracy deg.	Diameter ft.	Type	Maximum angular rate deg/sec	Year operational in DSIF			
				GS	W	J	Mobile station
0.05	10	Az-El	20				Dec 1960 (I)
0.01	85	Ha-Dec	1	Jan 1960(I)	Dec 1960(I)	Apr 1961(A)	
0.01	85	Az-El	2	May 1960(I)	Dec 1963(P)	Dec 1963(P)	
0.02	200-300		0.2-0.5	Dec 1963(P)	Dec 1966(P)	Dec 1966(P)	

b. DSIF antenna feeds - the antenna feeds listed in Table 8 are planned for specific program support. As a general rule, tracking antennas are circularly polarized, transmitter antennas are circularly polarized, and spacecraft antennas are linearly polarized. Tracking feeds utilized are exclusively of the simultaneous lobing type.

c. Typical DSIF system - a typical DSIF system embodying all of the capabilities discussed above is shown in Figure 2.

Table 8. DSIF Programmed Feed Capability

Frequency Mc	Output power	Type	Gain	Reflector diameter ft.	Est noise °K	Approx beam width deg	Year operational in DSIF GS	W	J	Mobile station
960/890	200w	Track Trans.	43.5/43	85	80	1.0	Jan 1960(I)	Nov 1960(I)	Apr 1961(A)	
960/890	25w	Track Trans.	22.5/22	10		9.0				Dec 1960(I)
960/890	10kw	Listen Trans.	45.8/45	85	60	0.9	Aug 1962(A)			
960/890	200w	Listen Trans.	45.8	85	60	0.85	Jan 1962(A)	Aug 1962(P)	Aug 1962(P)	
2295 ± 5 2115 ± 5	10kw	Track Trans.	51.8/51	85	50	0.4	Aug 1962(P)	Jan 1963(P)	Jan 1963(P)	
2295 2115 ± 5	10kw	Listen Trans.	52.8/52	85		0.38	Aug 1962(P)			
2295 ± 5 2115 ± 5	25w	Track Trans.	33/32	10		3.0				Jan 1963(P)
2115 ± 5	100kw	Trans.	51	85		0.4	Jan 1963(P)			
2115 ± 5	100kw	Trans.	62	200-300		0.13	Dec 1964(P)	Dec 1966(P)	Dec 1966(P)	
2295 ± 5		Track	61	200-300	15	0.15	Dec 1964(P)	Dec 1966(P)	Dec 1966(P)	

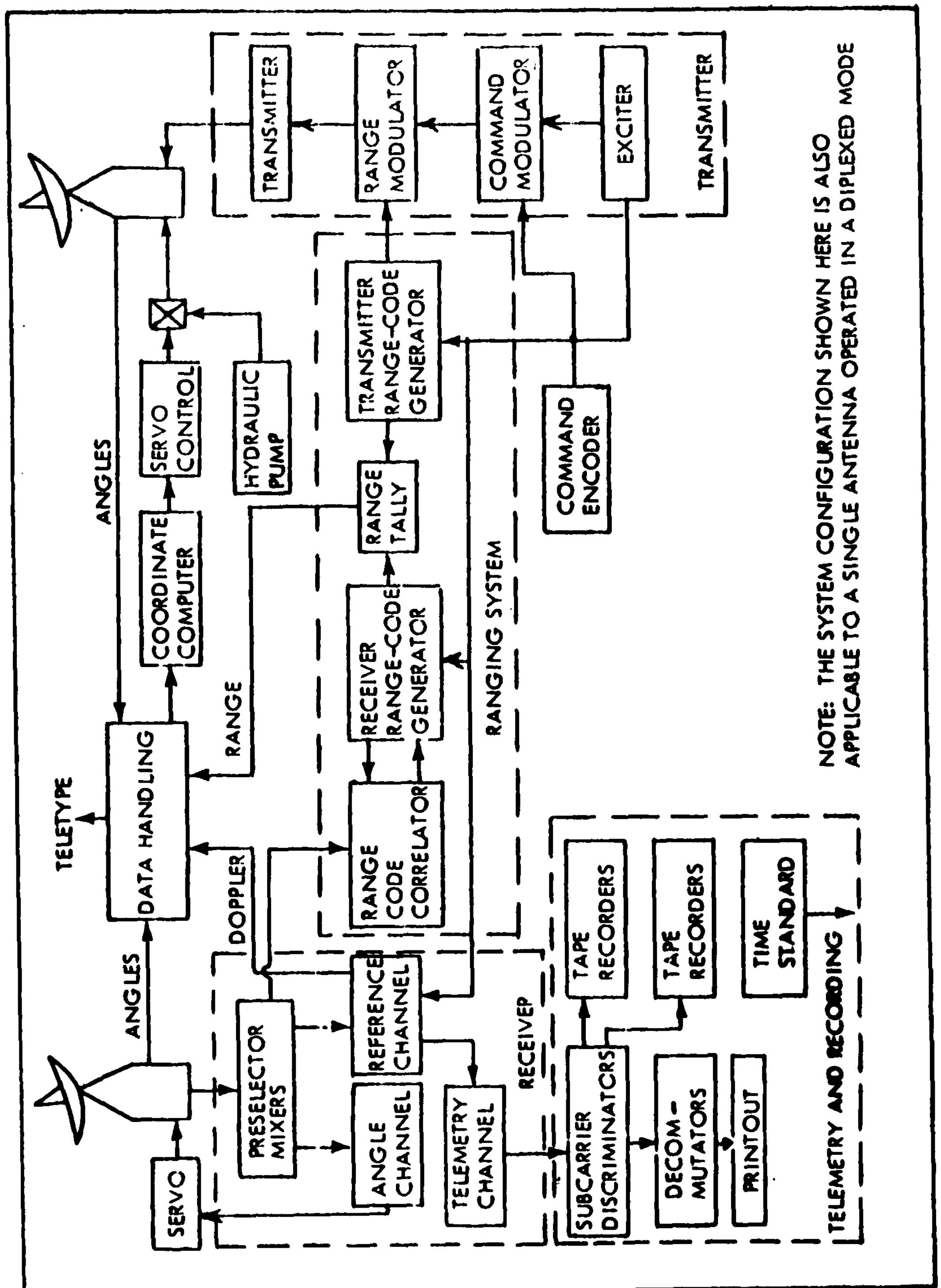

Figure 2. Typical Deep Space Tracking Station Block Diagram

5. DSIF Acquisition Procedures

DSIF spacecraft acquisition requirements can be separated into the following modes: pointing, frequency, and code acquisition, or combinations of them. The requirement for continuity of data from the spacecraft necessitates that acquisition be made as promptly as possible; to this end, the DSIF provides automatic scan equipment in the three modes to minimize acquisition time. However, certain minimum time requirements still exist which may effect the results of spacecraft experiments:

a. Angle - pointing information is usually provided for a tracking station; however, it is still necessary to search the area about which the probe position is predicted to be. Supplied ephemeris data are usually accurate to within a degree; however, as noted below, the combined requirement for both angle and frequency search may necessitate several minutes for complete acquisition.

b. One-way Doppler - lock in this mode can usually be achieved in 1 to 2 min. A priori information as to the expected received frequency considerably reduces the acquisition time to lock to the carrier. It is usually necessary, in any case, to be at least 3 to 6 db above threshold to establish carrier lock. Care must be exercised to avoid reference-channel phase lock on the subcarrier sidebands.

c. Two-way Doppler - two-way radio-frequency lock on a spacecraft transponder requires that the ground receiver first be locked on the spacecraft transmitter; then the ground-transmitter frequency is swept through the spacecraft-receiver frequency. The spacecraft receiver then acquires and switches from internal frequency control of the spacecraft transmitter to ground-transmitter frequency control, which then requires re-locking of the ground

receiver to the spacecraft transmitter. Periods involved could be in excess of 10 minutes.

d. Ranging - this is similar to two-way doppler; however, there is the additional complexity of acquiring range-code lock. Periods involved could be in excess of 15 min. The maximum tracking range is limited by the minimum possible loop-noise bandwidth of the carrier phase-locked system. Realization value for this parameter are as follows:

Year	Spacecraft Receiver	Ground Receiver
1961	100 cps	20 cps
1963	20 cps	3 cps
1965	10 cps	3 cps

e. Telemetry subcarrier - the acquisition time of subcarrier channels is usually dependent on the system used. In general, once the carrier has been acquired, the subcarrier acquisition and synchronization (if digital) will take several minutes.

D. Testing and Checkout

At the present time, approximately 10 hours are required to ready a tracking station to support a tracking mission. All checkout, calibration, and testing are performed manually and much data reduction and interpretation is necessary before the station is adjudged satisfactory.

A program is underway to automate many of the procedures now performed manually, and it is estimated that the total time necessary to ready the station will be less than one hour. Included in this automatic equipment will be go-no-go indicators, fault-locating indicators, automatic-calibration equipment, and checkout sequencers.

It is expected that the addition of this equipment will materially increase the operational reliability of the station and will enable the tracking stations to participate in a much higher percentage of total tracking hours.

V. DSIF MISSION SCHEDULES

The existing facilities and programmed expansion of the DSIF are expected to provide adequate tracking and communications capability for the lunar and planetary programs, for which JPL is responsible, during the next five years.

In general, it is expected that any one tracking station can, as a maximum, track 70% of the time, which leaves 30% of the time for maintenance. However, it is doubtful that this tracking percentage can be maintained during the next five years, when one considers the time required for modification or up-dating the tracking stations and the time required to change tracking feeds and equipment necessary to track other experiments within a 24-hour tracking period.

The types of space explorations to be supported include 24-hour satellites, lunar probes, planetary probes, and extra-ecliptic probes. As indicated previously, the Goldstone Station will also be utilized for research and development studies; it is expected that approximately half of the Goldstone activity will be directed to this end. Also it is expected that about 5% of the Woomera and Johannesburg schedule will be devoted to local research and development studies.

The tracking and communications scheduling requirements vary greatly, depending on the type of mission to be supported. A few examples of the requirements for specific missions are shown below.

1. High-density tracking requirements for several days
   a. Photographing lunar or planetary surfaces during encounter.
   b. Obtaining trajectory data for mid-course maneuvers.

2. Low-density tracking requirements for several months or years
   a. Deep-space ranging experiments for refinements of the astronomical unit.
   b. Particle or radiation experiments in deep-space (using data storage).
3. High-density tracking requirements for several weeks
   a. Mobile lunar explorations
   b. Dual-vehicle (satellite and soft-lander) planetary exploration.
4. High-density tracking requirements for several months
   a. Lunar mapping, using an orbital camera.
   b. Measurements of lunar or planetary surfaces by means of soft-landed capsules.

APPENDIX I. IRIG Telemetry Standards

A standard in the field of telemetry for guided missiles was established in 1948 by the Committee on Guided Missiles of the Research and Development Board (RDB), Department of Defense (DOD), and thereafter was revised and extended as a result of periodic reviews. Since the termination of RDB, the Inter-Range Instrumentation Group (IRIG) Steering Committee, representing the major DOD missile test ranges, has assigned the task of promulgating new or revised telemetry standards to the Inter-Range Telemetry Working Group (IRTWG).

The standards have been promulgated to further compatibility of airborne transmitting equipment and ground-receiving and data-handling equipment at missile test ranges. To this end, it is the recommendation of the IRIG Steering Committee that telemetry equipment at the test ranges conform to the standards.

The following information is condensed from IRIG document no. 103-56 on the FM/FM and FM/PM standard. It is the scheme used by JPL for the DSIF.

A. General

These telemetry systems are of the frequency division multiplex type. That is, an RF carrier is phase or frequency modulated by a group of subcarriers, each of a different frequency. The subcarriers are frequency modulated in a manner determined by the intelligence to be transmitted. One or more of the subcarriers may be modulated by a time division multiplex scheme (communication) to increase the number of data channels.

B. Subcarrier Bands

The 18 standard subcarrier bands are tabulated below. The given frequency response is based on a maximum deviation of ± 7.5% and a deviation ratio of 5. It is intended that the standard FM/FM receiving stations at the test ranges be capable of simultaneously demodulating a minimum of any 12 of these subcarrier signals.

Band	Center Frequency	Lower Limit	Upper Limit	Frequency Response
1	400 cps	370 cps	430 cps	6.0 cps
2	560	518	602	8.4
3	730	675	785	11
4	960	888	1032	14
5	1300	1202	1398	20
6	1700	1572	1828	25
7	2300	2127	2473	35
8	3000	2775	3225	45
9	3900	3607	4193	59
10	5400	4995	5805	81
11	7350	6799	7901	110
12	10,500	9712	11,288	160
13	14,500	13,412	15,588	220
14	22,000	20,350	23,650	330
15	30,000	27,750	32,250	450
16	40,000	37,000	43,000	600
17	52,500	48,560	56,440	790
18	70,000	64,750	75,250	1050

APPENDIX II. DSIF Literature Survey

1. JPL Technical Memorandum No. 33-26, July 15, 1960
"Deep Space Instrumentation Facility Specification"

   Volume I (100 pages) presents a system description with block diagrams and discusses the site survey problems and system checkout and monitoring equipment. Volume II (100 pages) is a dissertation on power, water, and personnel facilities at isolated desert locations. It discusses the physical DSIF system layout.

2. ARS Report No. 1669-61, Jan. 1961, 13 pp.
"Description of A Deep-Space Instrumentation Facility"
A very readable description of the present DSIF system.

3. JPL Technical Memorandum No. 33-27, February 13, 1961
"System Capabilities and Development Schedule of the Deep-Space Instrumentation Facility"

   Most of this document is reproduced in the preceding pages.

4. JPL Technical Release No. 34-10, January 29, 1960, 18 pp.
"Deep-Space Communications"

   Historical background of DSIF.

5. AAS Reprint No. 59-21, August 4, 1959, 29 pp.
"Design Techniques for Space Television"

   Signal to noise analysis of FM/PM phase locked loop used by DSIF.

6. Marvin Tepper, 1959 Rider book, 116 pp.
" Fundamentals of Radio Telemetry"

A simple-minded discussion of the over-all design of space telemetry systems.

7. JPL Industry Conference Proceedings, September 26, 1960
"Communications and Data Acquisition", pp 38-40

This is a discussion by the DSIF program manager of future equipment requirements of DSIF. This is summarized in Appendix III.

8. JPL Research Summaries
36-4, Vol. I, August 15, 1960, pp. 44-91

Discusses maser equipment at Goldstone and the doppler and data handling systems of DSIF. Article on Woomera installation. Analysis of ranging and telemetry systems.

36-6, Vol. I, December 15, 1960, pp. 18-63
Pictures and block diagrams of DSIF equipment.

36-7, Vol. I, February 15, 1961, pp. 31-99
More DSIF description and analysis with phtographs and block diagrams.

APPENDIX III BUSINESS OPPORTUNITIES IN DSIF

The following was reported by Eberhardt Rechtin, Telecommunications Division Director, DSIF program (see reference 7, Appendix II).

As has been mentioned, the DSIF is designed to permit the incorporation of advances in the state-of-the-art as soon as they become technically and financially feasible. This incorporation of new features into the system presents new business opportunity. Typical new equipments which have generated new businesses in the past are: phase-lock receivers, miniature microwave cavities, vibration-resistant airborn klystrons, FM modulators, etc. Items which we foresee for the future could be divided into two categories. The first category consists of items which represent continuing opportunity for existing businesses. This category would include:

1. Modulators and demodulators (phase-coherent, synchronous FM, or synchronous binary).
2. Ground antenna angle servo and control systems (hydraulic, electric, digital drive, display, and recording equipment).
3. Microwave optics (spacecraft and ground).
4. Transmitters (spacecraft, transistorized, 2300 Mc, 1-250 w radiated; ground, 2100 Mc, 20-100 kw).
5. Receivers (phase-locked low temperature, 2300 Mc, 10 Mc bandwidth).
6. Wideband telemetry (1-10 Mc).
7. Velocity equipment (high precision digital read-outs).
8. General test equipment (normally a standard procurement item).
9. Terminal instrumentation equipment for instrumenting and guiding vehicles which will land on the planets.
10. Atomic frequency standards for the DSIF.

The second category includes items in which there is more limited present industrial capacity and consequently some opportunity for new businesses. These would be:

1. Coders (pseudo-noise, digital, transistorized, 1 Mc rate), precision ranging.
2. Logic circuitry (acquisition, verification, data selection, replacement), ranging, command, data.
3. Unique spacecraft antennas (arrays, unfurlable, accurate to 1/16 in., 30 ft. diameter or equivalent).
4. Transponders (transistorized except for the final RF power amp., reliable acquisition, extremely long life).
5. Ranging equipment (coders, range tally equipment, search and acquisition circuits).
6. Quick reaction equipment (flexibility, quick change, simple tuning, general purpose recording). Automatic checkout and calibration of DSIF stations.
7. Advanced ground antennas.

The advanced antenna project is presently in the proposal phase for studies to be done both by JPL and by industrial contractors. Hardware procurement is not aniticipated before FY 1962 and must await the results of the studies and the approval of funds.

Bendix of Maryland is the contractor for the operation of Goldstone and our mobile station. The Weapons Research Establishment of Australia will operate the Woomera station. The South African Government will operate that station.

Certain problems of deep-space telecommunications are sufficiently unique that it pays to have a feasibility study before initiating expensive development. The purpose of many of the studies is to

help guide our various programs rather than to demonstra e the feasibility of some patented industrial device. The following items are of probable industrial interest.

1. Giant antennas (2300 Mc, 62 db, 10° K noise temperature fully steerable, about to be initiated).
2. Digital telemetry (a comparison of various industrial systems as applied to deep-space communications).
3. Secure coded digital command systems.
4. Automatic radar acquisition.
5. Telemetry from very deep space.
6. Terminal (landing and satelliting) instrumentation.
7. Long-life components and systems.
8. Unique spacecraft antennas.
9. Far side lobe characteristics of antennas (the physics of low-temperature antennas).
10. Molecular electronics, thin film techniques, cryogenics, and microminiaturization.
11. Adaptive non-linear control systems for large ground antennas.
12. Optical communications.

These studies may involve the construction of experimental equipment and may involve testing programs on existing NASA/JPL equipments.

In a sense, these studies indicate additional hardware items of interest a few years from now.